

# SEMICONDUCTOR STRUCTURE AND METHOD OF MAKING CONTACTS IN A SEMICONDUCTOR DEVICE

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## TECHNICAL FIELD

The present invention relates generally to the fabrication of integrated circuits, and more particularly to the formation of contacts in an integrated circuit.

## BACKGROUND OF THE INVENTION

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Most integrated circuit (IC) manufacturing processes typically include a number of manufacturing steps. Such steps may form, shape or otherwise modify a material, such as a conductive, semiconductive and/or insulating material, and thereby create an IC device.

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It can be desirable to reduce the number of steps in a manufacturing process. Such a reduction in process steps may have a number of beneficial results. The complexity of the overall manufacturing process may be reduced, making the fabrication of an IC easier to accomplish. A process yield may be increased, as the elimination of one or more steps may translate into fewer chances of forming defects. An IC may be fabricated in a shorter time period (cycle time is reduced). This can reduce the overall cost and/or increase manufacturing capacity.

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The elimination of particular IC manufacturing process steps may have other benefits. For some integrated circuits, it may be desirable to minimize an IC's exposure to temperature cycles (keeping as small a "thermal budget" as possible). Too many temperature cycles in a fabrication process may undesirably alter properties of structures formed within an IC. As just a few examples, if an IC includes metal-oxide-semiconductor (MOS) field effect transistors (FET), exceeding a thermal budget may result in shifts in the threshold voltage ( $V_t$ ) of such

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transistors. The reliability of such transistors may also be adversely affected, as transistor junctions may be more susceptible to failure mechanisms such as junction breakdown or "punch-through" current.

If an integrated circuit includes metal contacts to a doped semiconductor substrate, temperature cycles may result in higher contact resistance due to segregation of dopants at the metal-semiconductor interface and/or increased oxidation of the metal.

If an integrated circuit includes a substrate with diffusion regions formed with dopants, temperature cycles may increase diffusion region features due to out-diffusion of dopants.

Accordingly, reductions in the number of temperature cycles in an IC manufacturing process may produce more robust devices, avoid higher contact resistance, and/or allow for smaller device features.

Integrated circuits can typically include various layers of conductive and/or semiconductive materials (referred to herein collectively as "conducting" materials), as well as insulating materials. For example, an integrated circuit may include a substrate in which a number of active devices (such as transistors) may be formed. Such active devices may then be connected to one another by one or more conducting layers. The interconnecting conducting layers may be separated from one another by insulating layers.

A conducting layer may be formed from a single layer of material, or alternatively, include one or more conducting materials. As just a few examples, such a layer can include a conventionally doped polycrystalline silicon (polysilicon) and "silicide" (silicon-metal alloy). Alternatively, a conducting layer may include a titanium(Ti)-tungsten(W) alloy layered onto bulk aluminum, with an underlying barrier layer comprising Ti, Ti-nitride (TiN), or a Ti alloy.

Similarly, insulating layers can also be composites. As just one example, an insulating

layer may include a "doped" silicon dioxide ("oxide") and an "undoped" silicon oxide (undoped silicate glass or "USG"). The doped silicon oxide can include dopant elements, such as boron and phosphorous, while the undoped silicon oxide can be essentially free of dopant elements. Phosphorous doped silicon dioxide (phosphosilicate glass or "PSG") can provide advantageous ion gettering and/or step coverage properties. Boron and phosphorous doped silicon dioxide (borophosphosilicate glass or "BPSG") can also provide such advantages, and can be formed at lower temperatures, and thus can result in a more desirable thermal budget.

An insulating layer may perform a variety of functions in an integrated circuit. For example, an insulating layer may serve to electrically isolate one conducting layer or structure from another. Further, an insulating layer may serve as the surface on which subsequent layers are formed and patterned. Therefore, in many cases it may be desirable for an insulating layer to provide a relatively planar surface.

Different conducting layers may be connected to one another and/or to a substrate by contacts and/or vias. Contacts and/or vias can include contact holes that extend through one or more insulating layers. Conventionally, a contact may connect a conducting portion of a substrate to a conducting layer, while a via may connect two different conducting layers to one another.

A conventional way of forming a contact hole in one or more insulating layers may include lithography and etch steps. Lithography can be used to form an etch pattern over an insulating layer (that includes the location of contact holes). An etch step can transfer the pattern onto one or more lower situated insulating layers.

One concern with certain contact structures can be the alignment of a contact with a lower conducting layer. Because a contact is usually formed by etching a hole through an

insulating layer to an underlying conducting layer or structure. it is desirable that an etched hole to be aligned over the desired contact location in the lower conducting layer.

Further, it may be desirable to ensure that a contact hole is sufficiently insulated from other conductive lines. For example, in the case of semiconductor devices having insulated gate field effect transistors (IGFETs), such as metal-oxide-semiconductor FETs (MOSFETs), it is  
5 desirable to have a contact hole aligned with a source or drain, but at the same time, be sufficiently insulated from a conducting gate structure. A common approach to aligning contacts to conducting gate structures is a "self-aligned" contact. A self-aligned contact may include a lower conducting structure (such as a transistor gate) that includes a top insulating  
10 layer and a side insulating layer (such as a "sidewall"). With such an arrangement, a contact hole can be etched without a minimum spacing requirement with respect to the lower conducting structure.

Another concern regarding contacts and/or vias is contact area. The area of a contact can be of concern as a substrate on which a contact is formed may also include other important  
15 features, such as transistor channels, transistor isolation structures, transistor diffusion regions, and/or device wells. Thus, reductions in contact size can provide more area for other features and/or reduce the overall size of an integrated circuit device. Further, in many processes, contact area may have a minimum requirement in order to ensure a low enough contact resistance value. Thus, it is desirable that a contact forming process be capable of meeting a  
20 minimum contact resistance value.

Various factors may contribute to reducing contact area. In the case of "self-aligned" contacts, sidewalls and/or other structures, such as "etch" stop layers, may encroach on a contact area. Another factor is that of contact aspect ratio (AR). An aspect ratio can describe the ratio

between a contact height and width, when viewed in cross section. The higher the aspect ratio, the more difficult it may be to form the contact.

To better understand the formation of certain integrated circuit structures, including contacts structures, a conventional self-aligned contact (SAC) approach is set forth in FIGS. 7A-7H. FIGS. 7A-7H set forth a number of side cross-sectional views of a portion of an integrated circuit.

FIG. 7A shows a substrate **700** on which may be formed conducting structures **702**. A conducting structure **702** may be the gate of an insulated gate field effect transistor, such as a MOSFET. A substrate **700** may include doped monocrystalline silicon having various diffusion regions (not shown) formed therein. Further, an isolation structure **703** may be formed in a substrate **700**. A conducting structure **702** may include doped polycrystalline silicon ("poly") having a layer of silicide formed thereon.

A conducting structure may further include a top insulating structure **704** and sidewalls **706**. Sidewalls may be formed by the deposition of an insulating material and a subsequent anisotropic etch of the insulating material. As just one example, a top insulating structure **704** and sidewalls **706** may conventionally include silicon dioxide.

FIG. 7B shows an integrated circuit following the formation of a liner **708**. A liner **708** may protect a substrate **700** and a conducting structure **702** from a subsequent etch. In particular, a liner may prevent substantial etching of a sidewall and/or an isolation structure within a substrate **700**. Even more particularly, an isolation structure and a subsequently formed first insulating layer may both include silicon dioxide. Thus, an etch through a first insulating layer (such as a contact hole forming etch) may have no substantial selectivity with an isolation structure. Consequently, without a liner **708**, such an etch may "gouge" an isolation structure.

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Such gouging can result in leakage current that may adversely affect integrated circuit reliability and/or the characteristics of circuit devices (such as transistors).

A liner may include silicon nitride. A drawback to a silicon nitride liner can be the temperature at which such a layer may be formed, which may increase a thermal budget.

5        FIG. 7C shows an integrated circuit following the formation of a first insulating layer **710**. A first insulating layer **710** can insulate a substrate **700** and/or a conducting structure **702** from a subsequently formed contact and/or interconnect pattern. A first insulating layer may include BPSG deposited by a plasma enhanced chemical vapor deposition (PECVD) step.

10        BPSG may be selected as a conventional choice for a first insulating material due to its low "reflow" temperature. Reflow involves heating a layer so that the layer becomes more malleable, and thus flows to fill in the lowest lying space. The reflowed layer may thus become more planar than the originally deposited layer. A reflow step may also add to the thermal budget of a manufacturing process.

15        Generally, the higher the concentration of boron and phosphorous, the lower the reflow temperature of the BPSG. BPSG is also desirable in that it can be a getterer for undesirable mobile ions, such as sodium, that can result in reliability failures in integrated circuits. Unfortunately, BPSG can have undesirable properties as well. The boron ions within BPSG can out-diffuse from the BPSG into the substrate, unintentionally doping the substrate. In addition, boron dopants can out-diffuse into polysilicon lines, unintentionally lowering or raising the  
20        conductivity of such lines.

While BPSG provides a relatively low reflow temperature, there are limits to BPSG reflow temperatures. Such limits arise out of the adverse effects presented by highly doped BPSG. Relatively high concentrations of boron (e.g., over 5% by weight) may make the

resulting BPSG film unstable and hygroscopic (attract moisture). Unstable BPSG can crack and/or form boron rich crystals. BPSG cracks can ruin the insulating properties of the BPSG, while boron rich crystals may result in non-planar surfaces and/or micro-masking etch defects. The hygroscopic nature of conventional high-concentration BPSG can create bubbles, or result  
5 in forming one or more phosphorous-based acids, which may corrode conductive lines, such as those containing aluminum.

A BPSG layer may also be densified. A densification step may be incorporated into a reflow step or occur prior to, or after a reflow step. Densification can increase the stability of an insulating layer. Densification may be accomplished by raising the temperature of a BPSG  
10 layer following its deposition. Thus, densification of a BPSG may also contribute to the thermal budget of a process.

Another insulating material is phosphorous doped glass (phosphosilicate glass, or "PSG"). PSG is generally not used in conventional approaches due to its higher flow temperature. The flow temperature can be lowered by increasing the concentration of  
15 phosphorous, but higher concentrations of conventional PSG may have the drawbacks discussed above, including the formation of bubbles and/or acids. Accordingly, conventional PSG approaches may not be used as first insulating layer as such approaches can result in a higher thermal budget than those that include BPSG.

A first insulating layer **710** may also be planarized. An integrated circuit following a  
20 planarization step is shown in FIG. 7D. A planarization step may include chemical-mechanical polishing (CMP).

Following a planarization step, a "cap" insulating layer **712** may be formed over a first insulating layer **710**. A cap insulating layer **712** may serve to prevent the migration of dopants

within a first insulating layer **710** and/or prevent moisture from migrating into a first insulating layer **710**. A cap insulating layer **712** may also provide a more stable surface for subsequent layers. A conventional cap insulating layer **712** may include undoped silicon dioxide. An integrated circuit following the formation of a cap insulating layer is shown in FIG. 7E.

5        FIG. 7F shows an integrated circuit following the formation of a contact etch mask **714**. A contact etch mask **714** may be formed with conventional photolithographic techniques, and include developed photoresist with mask openings **716** that can expose portions of a cap insulating layer **712**.

10        With a contact etch mask **714** formed over a cap insulating layer **712** and first insulating layer **710**, a contact hole **718** may be etched to a substrate **700** that is self-aligned with respect to a conductive structure **702**. In the event a cap insulating layer **712** and first insulating layer **710** are undoped silicon dioxide and BPSG, respectively, a formation of contact hole may include a two step etch process. A first etch may be optimized for removal of undoped silicon dioxide and a second etch may be optimized for the removal of BPSG. An integrated circuit following  
15        the formation of a contact hole is shown in FIG. 7G.

20        An etch that forms a contact hole **718** through a first insulating layer **710** and/or a cap insulating layer **712** may be selective between a liner **708** and a first insulating layer **710**. As shown in FIG. 7G, following such an etch, a liner **708** may remain substantially intact, and protect a substrate **700**, and/or a sidewall **706**, and/or a top insulating structure **704** from such a contact etch. In the event a first insulating layer **710** includes BPSG and a liner **708** includes silicon nitride, such an etch may be an "oxide" etch. An oxide etch may etch a layer of silicon dioxide or doped silicon dioxide at a substantially faster rate than a layer of silicon nitride.

A liner etch may then remove portions of a liner **708**. An integrated circuit following a



liner etch is shown in FIG. 7H. A liner opening 720 may be formed, exposing a portion of a substrate 700 forming a contact area. However, a contact area width, shown by measuring bar 722, may be limited by residual portions of a liner 708.

As feature sizes in ICs continue to shrink, conventional approaches to forming contacts may only provide limited results. It would be desirable to arrive at some way of increasing contact area over conventional approaches, such as that shown in FIGS. 7A to 7H.

It would also be desirable to reduce the thermal budget of an IC manufacturing process. Such a reduction may result in more reliable devices and smaller IC features.

It would also be desirable to reduce the number of steps in an IC manufacturing process. Such a reduction may result in faster cycle times, provide a simpler process and accrue the various other benefits thereof.

#### SUMMARY OF THE INVENTION

The various disclosed embodiments set forth methods of forming self-aligned contacts. Such methods may form contacts with features that are less than 0.20 microns ( $\mu\text{m}$ ) without forming a liner to protecting lower conducting structure, such as a substrate and/or a transistor gate.

According to one aspect of the embodiments, self-aligned contacts may be formed in a first insulating layer that is not densified.

According to another aspect of the embodiments, a first insulating layer may include phosphosilicate glass (PSG).

According to another aspect of the embodiments, contacts may be formed to a substrate through a first insulating layer that includes silicon dioxide. Such contacts are self-



## DETAILED DESCRIPTION OF THE EMBODIMENTS

Various embodiments of the present invention will now be described in conjunction with a number of charts and diagrams. The embodiments set forth approaches to forming a self-aligned contact in an integrated circuit. Such a contact may be formed with fewer  
5 temperature cycles than conventional approaches. Alternatively, or in addition, such a contact may be formed without a liner, and thus may provide greater contact area.

Referring now to FIG. 1, a flow diagram is set forth illustrating method of forming self-aligned contacts according to a first embodiment. The first embodiment is designated by the general reference character **100**, and may include forming a conducting structure with  
10 sidewalls (step **102**). An integrated circuit following such a step is set forth in FIG. 2A. FIG. 2A includes a substrate **200** having an isolation structure **202**. A substrate **200** may include a conductive or semiconductive material (referred to herein collectively as "conducting materials"), as just a few examples. An isolation structure **202** may be formed by a number of techniques, including shallow trench isolation (STI), recessed oxide isolation (ROI), or  
15 local oxidation of silicon (LOCOS), to name but a few examples.

As also shown in FIG. 2A, a conducting structure **204** may be formed on a substrate **200** that includes an insulating sidewall **206**. An insulating sidewall (also referred to as a "spacer") may preferably comprise a material such as silicon dioxide ( $\text{SiO}_2$ ), more preferably silicon oxynitride ( $\text{Si}_x\text{N}_y\text{O}_z$ ), and even more preferably silicon nitride ( $\text{Si}_3\text{N}_4$ ).

20 A first insulating layer may be formed (step **104**) over a conducting structure and sidewall. An integrated circuit following a step **104** is shown in FIG. 2B. A first insulating layer **208** may provide a different etch response than a sidewall when exposed to a contact etch. As just one example, a first insulating layer may include silicon dioxide while a

sidewall may include silicon oxynitride and/or silicon nitride.

A first insulating layer **208** may be formed without first forming a protective liner. As will be discussed below, by not including a protective liner, a resulting contact may be larger than a conventionally formed contact.

5        A step **104** may particularly include depositing a layer of silicon dioxide that includes relatively high levels of phosphorous. Relatively high levels of phosphorous may include concentrations of phosphorous that exceed those used in other conventional insulating layers, such as borophosphosilicate glass (BPSG). For some approaches, relatively high levels of phosphorous may include levels that are greater than 5% by weight. More substantial  
10    departures from conventional approaches may include phosphorous concentrations that are greater than 7% by weight.

A first insulating layer may further be formed with high density plasma (HDP) deposition techniques. A high density plasma may include a charge density that generally exceeds that used in conventional insulating layer deposition approaches (e.g., charge  
15    densities used in conventional plasma enhanced and plasma assisted chemical vapor deposition (PECVD and PACVD)). For example, a high density plasma may include a charge density that exceeds that used to deposit conventional PECVD BPSG layers. For some approaches, a high density plasma may include charge densities that generally exceed  
20     $10^7$  charged particles per  $\text{cm}^3$ , and more specifically, charge densities in the general range of  $10^9$ - $10^{12}$  charged particles per  $\text{cm}^3$ .

While a first insulating layer **208** may include other dopants, a first insulating layer **208** may be doped substantially only with phosphorous to form phosphosilicate glass ("PSG"). A first insulating layer **208** of PSG may not include any, or only insubstantial

amounts of boron, and thus may be less susceptible to the adverse effects of boron.

It is understood that while the various embodiments refer to insulating and conducting layers as "first" such layers, such a term should not be construed as being limited to a first layer formed in a manufacturing process. Other layers may be formed below and/or prior to  
5 a "first" layer.

A first embodiment **100** may further include a step of forming a contact hole through a first insulating layer that is not densified (step **106**). The first embodiment **100** may thus not include a step that densifies a first insulating layer. This can avoid a thermal cycle in a conventional process, and thus may reduce the thermal budget of such a process. An  
10 example of an integrated circuit following a step **106** is shown in FIG. 2C, and includes a contact hole **210**.

A step **106** may preferably include a substantially anisotropic reactive ion etch (RIE). A RIE etch may etch a first insulating layer **208** at a substantially faster rate than a sidewall **206**. A portion of a substrate **200** may be exposed, forming a contact area **212**.

15 A contact area **212** may have larger dimensions than a conventional method that includes a liner. A volume occupied by a residual liner is shown in FIG. 2C as a dashed line **214**. A contact width formed by a conventional method is shown by measuring bar **216**. A contact width formed by a first embodiment is shown by measuring bar **218**. A measuring bar **218** may be larger than a measuring bar **216**, as a residual liner **214** is not present to  
20 encroach into a contact area **212**.

In addition or alternatively, a contact etch according to a step **106** may be selective between an isolation structure **202** and a first insulating layer **208**. In this way, such a contact etch may remove a first insulating layer **208** but not remove substantial amounts of

an isolation structure **202**. Thus, a method according to a first embodiment may skip a liner formation step that may be conventionally used to preserve the integrity of an underlying isolation structure (such as **202**).

A first embodiment **100** may further include forming a contact structure in a contact  
5 hole (step **108**). Such a step may include, as just one example, depositing one or more conductive materials into a contact hole. Conductive materials may be subsequently patterned and/or planarized to form a contact structure. An integrated circuit following a step **108** is shown in FIG. 2D. A contact structure **220** is shown formed within a contact hole **210**.

10 In this way, a first embodiment **100** may form a contact through a first insulating layer that does undergo a densification and/or reflow step. This may eliminate a thermal cycle in a manufacturing process. In addition or alternatively, a liner formation step may be omitted. This may also eliminate a thermal cycle in a manufacturing process and/or result in larger contact area. In addition or alternatively, an etch that may form a contact hole through  
15 a first insulating layer may be selective between the first insulating layer and a lower isolation structure. A lower isolation structure may thus be preserved without forming a protective liner.

A second embodiment is shown in flow diagram form in FIG. 3. A second embodiment is designated by the general reference character **300**, and may include forming  
20 conductive structures adjacent to one another that include sidewalls (step **302**). An integrated circuit following a step **302** is shown in FIG. 4A.

FIG. 4A includes a substrate **400** on which may be formed adjacent conducting structures **402-1** to **402-2**. Conducting structures **402-1** to **402-2** may include insulating

sidewalls **404-1** and **404-2** and top insulating structures **406-1** and **406-2**. A substrate **400** may include an isolation structure **408**.

Features and spacings of structures formed in a step **302** may have sizes that are conventionally formed with a protective liner. For example, sidewalls (**404-1** and **404-2**) and/or top insulating structures (**406-1** and **406-2**) can have a thickness that may not adequately protect a conducting structure (**402-1** and **402-2**) in a conventional self-aligned contact process. As one particular example, a lateral space between conducting structures (**402-1** and **402-2**) may be 0.4 microns ( $\mu\text{m}$ ) or less, preferably 0.35  $\mu\text{m}$  or less, or more preferably 0.3  $\mu\text{m}$  or less. A lateral base width of sidewalls (**404-1** and **404-2**) may be 0.15  $\mu\text{m}$  or less, preferably 0.10  $\mu\text{m}$  or less, or even more preferably 0.07  $\mu\text{m}$  or less.

A substrate **400**, conducting structures (**402-1** and **402-2**), sidewalls (**404-1** and **404-2**), and isolation structure **408** may include the same preferred formation methods and materials and/or be subject to the same variations discussed in conjunction with FIG. 2A. A top insulating structure (**406-1** and **406-2**) may preferably comprise a material such as silicon dioxide ( $\text{SiO}_2$ ), more preferably silicon oxynitride ( $\text{Si}_x\text{N}_y\text{O}_z$ ), and even more preferably silicon nitride ( $\text{Si}_3\text{N}_4$ ).

The second embodiment **300** may further include forming a first insulating layer without first forming a liner (step **304**). Thus, unlike a conventional approach that may deposit a liner to protect small sized features from a subsequent etch, a second embodiment **300** may not include such a step. By excluding such a step, a second embodiment **300** may eliminate a temperature cycle and thereby reduce the thermal budget of a manufacturing process. An elimination of a liner step may be particularly advantageous as many conventional approaches include silicon nitride liners, and the deposition of silicon nitride

may include relatively high temperatures.

An integrated circuit following a step **304** is shown in FIG. 4B. A first insulating layer **410** may be formed over a substrate **400**, including between adjacent sidewalls (**404-1** and **404-2**). A first insulating layer **410** may include the same preferred formation methods and materials and/or be subject to the same variations discussed in conjunction with first insulating layer **208** in FIG. 2B. A first insulating layer **410** may also preferably provide a different etch response than a sidewall and/or a top insulating structure when exposed to a contact etch.

It is understood that by not including a liner formation step, a space between adjacent sidewalls (**404-1** and **404-2**) may be larger than a conventional approach, as a liner is not present that encroaches into such a space. This is illustrated in FIG. 4B by a dashed line **412** that can represent a space that would be occupied by a liner. A conventional length measurement, that takes liner encroachment into account can be shown by measurement bar **414**. A length measurement of a second embodiment can be shown by measurement bar **416**. In the particular arrangement of FIG. 4B, a liner **412** may encroach from two sides.

A second embodiment **300** may continue by etching a contact hole between adjacent conductive structures (step **306**). An integrated circuit following a step **306** is shown in FIG. 4C. A contact hole **418** may be formed through a first insulating layer **410**, exposing a portion of a substrate **400**. An exposed portion of a substrate **400** may be a contact area **420**. A contact hole **418** may be formed by the same preferred method and/or be subject to the same variations discussed in conjunction with FIG. 2C.

It is noted that because the second embodiment **300** does not include a liner forming step, a contact hole to a substrate may be formed without an additional liner opening step.



This can lead to a process having fewer steps than a conventional approach.

It is also noted that because the second embodiment **300** does not include a liner forming step, a contact area **420** may be larger than a contact area formed with a conventional approach. In a conventional approach, a liner may encroach into a contact area.

5 Thus, measurement bar **414** may represent a width measurement of a resulting contact area of a conventional approach. In contrast, in a second embodiment **300**, there is no liner, thus a contact area **420** may be larger than a conventional approach. Measurement bar **416** may represent a width measurement of contact area **420**.

10 Once a contact hole **418** is formed, a contact structure may be formed. As shown in FIG. 4D, a contact structure **422** may be self-aligned with respect to adjacent conducting structures **402-1** and **402-2**.

A contact structure may be formed in the same fashion, include the same materials and/or be subject to the same variations discussed in conjunction with contact structure **220** of FIG. 2D. A contact structure is shown as item **422** in FIG. 4D.

15 In this way, a second embodiment **300** may form a contact through adjacent conducting structures without including a liner formation step. This may eliminate a thermal cycle in a manufacturing process and/or result in a larger contact area than a conventional approach.

Referring now to FIG. 5, a third embodiment is set forth in a flow diagram designated  
20 by the general reference character **500**. A third embodiment **500** may include forming a gate etch mask (step **502**). As shown in FIG. 6A, an integrated circuit may include a substrate **600** having a gate layer **602** formed thereon and an isolation structure **604** formed therein. A gate layer **602** may include a gate insulator layer **606**, a gate conducting layer **608**, and a gate

top insulating layer **610**.

In one particular arrangement, a gate insulator layer **606** may comprise silicon dioxide, and/or silicon nitride, and/or silicon oxynitride, to name just a few examples. A gate conducting layer **608** may include a conductive and/or semiconductive material. In a more particular example, gate conducting layer **608** may include doped polysilicon and a layer of silicide. A gate top insulating layer **610** may include silicon oxynitride, more preferably silicon nitride, to name just two examples. A gate top insulating layer **610** material may be selected to provide a different etch response than a subsequently formed first insulating layer.

FIG. 6A also includes a gate etch mask **612** formed over a gate layer **602**. A gate etch mask **612** may include a gate pattern. A gate pattern may be formed by conventional photolithographic techniques. Gate mask portions may be situated over locations where a gate may be formed. Gate mask openings may be situated over locations where a gate layer **602** may be removed.

A third embodiment **500** may transfer a gate pattern from a gate etch mask to a gate layer with a gate structure etch (step **504**). A gate structure etch may preferably include one or more a reactive ion etches (RIE), as just one example. An integrated circuit following a step **504** is shown in FIG. 6B. Portions of a gate layer that are exposed by a gate etch mask **612** can be removed, forming adjacent gate structures **614-1** and **614-2**. A gate etch mask **612** may then be removed.

As shown in FIG. 5, a sidewall layer may be deposited (step **506**). As shown in FIG. 6C, a sidewall layer **616** may be formed over gate structures (**614-1** and **614-2**). A sidewall layer **616** material, like a gate top insulating layer **610** material, may be selected to provide a different etch response than a subsequently formed first insulating layer.

A sidewall insulating layer may preferably be formed by chemical vapor deposition (CVD) comprising a silicon source, such as silane, preferably a chlorosilane ( $\text{SiH}_x\text{Cl}_3$ ), more preferably dichlorosilane ( $\text{SiCl}_2\text{H}_2$ ), and a nitrogen source, such as nitrogen ( $\text{N}_2$ ), nitrous oxide ( $\text{N}_2\text{O}$ ), preferably ammonia ( $\text{NH}_3$ ). In one particular approach, silicon source flows  
5 into a deposition chamber may be in the general range of 5-100 standard  $\text{cm}^3$  per minute (sccm), preferably 10-50 sccm, more preferably 25-35 sccm. Nitrogen source flows may be in the general range of 10-300 sccm, preferably 50-200 sccm, more preferably 80-110 sccm.

A sidewall insulating layer of CVD nitrogen may further be deposited at a temperature in the general range of 600-950 °C, preferably 650-800 °C, more preferably 725-  
10 775 °C. Deposition chamber pressure may be in the general range of 5-500 milliTorr (mT), preferably 50-200 mT, more preferably 80-120 mT. Deposition time may be in the general range of 20-100 minutes (min), preferably 30-70 min, more preferably 40-60 min.

Of course, the various deposition parameters set forth should not be construed as limiting the invention thereto. As just a few examples, deposition times and/or temperatures  
15 and/or pressures may be selected such that the target silicon nitride level may be achieved. Further, while a CVD method of depositing silicon nitride is described, other methods may be employed. As just a few examples, silicon nitride may be deposited by high density plasma chemical vapor deposition (HDP CVD), or plasma assisted or enhanced CVD (PECVD/PACVD).

20 Following the deposition of a sidewall layer, sidewalls may be formed (step **508**). Formation of sidewalls may include removing portion of a sidewall layer with an anisotropic etch. An integrated circuit following a step **508** is shown in FIG. 6D. Following a sidewall formation step, sidewalls **618-1** and **618-2** may be formed on gate structures **614-1** and **614-**

2, respectively.

A first insulating layer may then be deposited without first forming a liner (step **510**). Thus, a third embodiment **500** may advantageously avoid a step in many conventional processes. Further, a more favorable thermal budget may result. An integrated circuit  
5 following a step **510** is shown in FIG. 6E. A first insulating layer **620** may be formed over a substrate **600** and gate structures (**614-1** and **614-2**). A first insulating layer **620** may include the same preferred formation methods and materials and/or be subject to the same variations discussed in conjunction with first insulating layer **208** in FIG. 2B.

As noted above, a first insulating layer **620** material may be selected to provide a  
10 different etch response than sidewalls and/or a top insulating layer when exposed to a contact etch. As one particular example, a first insulating layer **620** may include silicon oxide while sidewalls and/or a top insulating layer may include silicon oxynitride and/or silicon nitride. More particularly, a first insulating layer **620** may include HDP PSG, as described above, while sidewalls and/or a top insulating layer may include silicon nitride. HDP PSG may not  
15 require a reflow and/or densification step, and thus may provide a simpler manufacturing process and/or a process with an advantageously smaller thermal budget than a conventional approach that reflows or densifies such a layer.

In one particular approach to forming a first insulating layer of HDP PSG, a high density plasma may include low frequency power in a general range of 4000-4500 Watts and  
20 high frequency power in a general range of 1200-1500 Watts. PSG may be formed from a plasma comprising a mixture of a silicon source such as silane ( $\text{SiH}_4$ ) or a chlorosilane  $\text{SiH}_x\text{Cl}_y$ , where  $x+y=4$  for example, an oxygen atom source such as ( $\text{O}_2$ ), ozone ( $\text{O}_3$ ) or nitrous oxide ( $\text{N}_2\text{O}$ ) for example, and a phosphorous source such as phosphine ( $\text{PH}_3$ ).

$\text{PH}_a\text{Cl}_b$ , a methyl phosphine  $\text{PH}_a(\text{CH}_3)_b$ , or an ethyl phosphine  $\text{PH}_a(\text{C}_2\text{H}_5)_b$  where  $a+b=3$  for example. In one particular approach, silicon source flows into the plasma chamber may be in the general range of 5-100 standard  $\text{cm}^3$  per minute (sccm), preferably 10-50 sccm, more preferably 23-30 sccm. Oxygen atom source flows may be in the general range of 20-1000 sccm, preferably 100-500 sccm, more preferably 350-400 sccm. Phosphorous source flows may be in the general range of 10-500 sccm, preferably 50-350 sccm, more preferably 170-200 sccm. Argon may also flow in the reaction chamber at a rate in the general range of 25-40 sccm.

The flow ratios of the silicon source and phosphorous source may be selected from the mathematical possibilities supported by the above ranges such that the target phosphorous level is achieved. However, preferred silicon source to phosphorous source flow rate ratios may be in the general range of 1:20 to 1:2, more preferably 1:10 to 1:5.

Of course, the various power levels and flow rates recited should not be construed as limiting the invention thereto. A relatively high level of phosphorous and high density plasma may include the same general criteria described in conjunction with step **104** of FIG. 1. A level of phosphorous in an HDP PSG layer may be in the general range of 3-15 % phosphorous (P) (by weight), preferably 4-12 % P, more preferably 5-9 % P.

A method of forming a HDP PSG layer in an integrated circuit is disclosed in commonly owned, co-pending U.S. Patent Application No. 09/300,817 entitled METHODS OF FILLING CONSTRAINED SPACES WITH INSULATING MATERIALS AND/OR OF FORMING CONTACT HOLES AND/OR CONTACTS IN AN INTEGRATED CIRCUIT, the contents of which are incorporated by reference herein.

Once a first insulating layer has been deposited, it may be planarized (step **512**).

Planarization may be accomplished by a chemical-mechanical polishing (CMP) step, to name just one example. Alternatively, planarizing may be accomplished by an isotropic etching step, or by a relatively low temperature and/or short duration reflow step, but CMP is preferred. An integrated circuit following a step **512** is set forth in FIG. 6F. A first insulating layer **620** may include a substantially planar surface.

A third embodiment **500** may also include depositing a second insulating layer over the first insulating layer (step **514**). A second insulating layer can form all or part of a "hard" etch mask for a first insulating layer. A second insulating layer may include silicon dioxide, preferably undoped silicon dioxide (undoped silicate glass or "USG"). A second insulating layer may be deposited using chemical vapor deposition (CVD), or plasma enhanced or plasma assisted CVD (PECVD and PACVD), or high density plasma (HDP) deposition, to name but a few examples. Preferably, tetraethylorthosilicate (TEOS) may be a source material in such a deposition step. In some arrangements, a second insulating layer may also be planarized.

FIG. 6G shows a portion of a semiconductor device following the deposition of a second insulating layer **622**. A second insulating layer **622** can be deposited over (but not necessarily on) a first insulating layer **620**.

A third embodiment **500** may then form a contact etch mask (step **516**). A step **516** may include conventional photolithographic techniques. A layer of photoresist may be patterned and developed over a second insulating layer and form a contact hole pattern in a photoresist material.

FIG. 6H shows an integrated circuit following the formation of a contact etch mask **624**. A contact etch mask **624** may include mask openings **626**. Mask openings **626** may be

situated over locations where a contact hole may be formed.

A third embodiment **500** may further include a step that forms a hard etch mask that includes a second insulating layer (step **518**). In one particular arrangement, a step **518** may include a RIE step having a high degree of selectivity between a second insulating layer and  
5 a contact etch mask. This can transfer a contact hole pattern in a contact etch mask, to a second insulating layer **622**. A semiconductor device following such a step **518** is shown in FIG. 6I.

In FIG. 6I, portions of a second insulating layer have been removed according to a contact etch mask **624**. Consequently, a hard etch mask **628** has been formed that includes a  
10 second insulating layer **622**. In the particular arrangement of FIG. 6I, a hard etch mask can include a hard mask openings **630**. A hard mask opening **630** may be situated over a location where a contact hole may be formed, preferably a self-aligned contact hole.

A third embodiment **500** may further include removing a contact etch mask (step **520**). In the event a contact etch mask includes a photoresist, a step **520** may include  
15 "ashing" with a plasma etch, or the like. Of course, other conventional removal techniques can be utilized, according to the particular type of contact etch mask.

FIG. 6J illustrates an integrated circuit following the removal of a contact etch mask **624**. A hard etch mask **628** remains over a first insulating layer **620**. It is noted that removing a contact etch mask **624** can result in a hard self-aligned contact etch mask that  
20 produces a smaller aspect ratio for contact holes than other conventional approaches, such as those that may use photoresist as an etch mask.

A method of forming contact with a hard etch mask is disclosed in commonly owned co-pending U.S. Patent Application No. 09/326,432 entitled METHOD AND STRUCTURE

FOR MAKING SELF-ALIGNED CONTACTS, the contents of which are incorporated by reference herein.

With a hard etch mask formed over a first insulating layer, a third embodiment **500** may continue with a self-aligned contact etch (step **522**). A self-aligned contact (SAC) etch  
5 may form a contact hole through a first insulating layer to a substrate. A SAC etch may preferably be a reactive ion etch (RIE) that includes one or more chlori- and/or fluorinated carbon molecules as an activating gas. Such gases may include  $\text{CFCl}_3$ ,  $\text{CF}_2\text{Cl}_2$ ,  $\text{CF}_3\text{Cl}$ ,  $\text{CF}_4$ ,  $\text{CHF}_3$ ,  $\text{C}_2\text{ClF}_5$ , and/or  $\text{C}_2\text{H}_2\text{F}_4$ , as just a few examples.

In a preferred approach, a SAC RIE may form a contact hole through a PSG layer.  
10 Such a RIE may preferably include trifluoromethane ( $\text{CHF}_3$ ) and tetrafluoroethane ( $\text{C}_2\text{H}_2\text{F}_4$ ). A flow rate for  $\text{C}_2\text{H}_2\text{F}_4$  may be in the general range 1-20 sccm, preferably 3-15 sccm, more preferably 5-7 sccm. A flow rate for  $\text{CHF}_3$  may be in the general range of 5-200 sccm, preferably 10-100, more preferably 30-50 sccm. A RIE may also include the introduction of an inert gas such as argon (Ar) and/or xenon (Xe), preferably Ar. A flow rate for Ar may be  
15 in the general range of 5-300 sccm, preferably 50-200, more preferably 110-140 sccm.

A preferred SAC RIE may also include radio frequency (RF) power values in the general range of 100-1000 Watts (W), preferably 200-700 W, more preferably 250-350 W. A bias to a surface on which a wafer may be situated, such as a RIE chamber cathode, may be in the general range of 100-1500 volts (V), preferably 500-1000 V, more preferably 650-  
20 750 V. Preferably, a bias voltage may be a negative voltage. A RIE chamber pressure may be in the general range of 10-200 mT, preferably 30-100 mT, more preferably 50-60 mT. A RIE chamber temperature may be in the general range of 0-35 °C, preferably 5-30 °C, more preferably 10-20 °C. In one particular arrangement, integrated circuits are formed on wafer



that may be situated on a "chuck" within a deposition chamber. A chuck may be cooled by the application of helium. A helium cooling pressure may be in the general range of 1-50 Torr, preferably 5-20 Torr, more preferably about 50 Torr.

RIE etch times at the more preferred parameters referred to above may be in the  
5 general range of 80-200 seconds (s), preferably 100-200 s, more preferably 140-160 s.

A preferred contact etch may have desirable selectivities between various structures in an integrated circuit. For example, an etch selectivity between a first insulating layer and a sidewall may be 10:1 or greater, preferably 20:1 or greater, more preferably 25:1 or greater. Such an etch selectivity can allow a sidewall (such as **618-1** and **618-2**) to protect a gate  
10 portion of a gate structure (such as **614-1** to **614-2**), essentially eliminating the need for a protective liner. Preferably, a first insulating layer includes HDP PSG and a sidewall includes silicon nitride.

In addition, or alternatively, an etch selectivity between a first insulating layer and a hard mask may be in the general range of 50:1 or greater, preferably 75:1 or greater, more  
15 preferably 100:1 or greater. Such an etch selectivity can allow a formation of a contact hole without removing substantial portions of a hard mask. Preferably a first insulating layer includes HDP PSG and a sidewall includes TEOS USG.

In addition, or alternatively, an etch selectivity between a first insulating layer and a substrate may be in the general range of 100:1 or greater, preferably 150:1 or greater, more  
20 preferably 200:1 or greater. Such an etch selectivity can allow a formation of a contact hole without the need for a liner to protect a substrate. Preferably, a first insulating layer includes HDP PSG and a substrate includes conventionally doped monocrystalline silicon.

In addition, or alternatively, an etch selectivity between a first insulating layer and a

substrate isolation structure may be equal to or greater than the above-described selectivity between a first insulating layer and TEOS USG. Such an etch selectivity may essentially eliminate the need for a liner to protect an isolation structure. Preferably, a first insulating layer includes HDP PSG and an isolation structure includes silicon dioxide.

5           An integrated circuit following a SAC etch is shown in FIG. 6K. A contact hole **632** may extend through a first insulating layer **620** and expose a portion of a substrate **600**, and thereby form a contact area **634**. A contact area **634** may be larger than an area formed in a conventional process that includes a liner, as remaining residual liners will not encroach into a contact area **634**. To illustrate this aspect of a third embodiment **600**, dashed lines **636** are  
10       included in FIG. 6K to illustrate the space residual liners could occupy.

          In this way, a third embodiment **500** may provide larger contacts between adjacent conducting structures. It is noted that an adjacent gate arrangement such as that set forth in FIGS. 6A to 6K may be present in many integrated circuit arrangements. As just a few examples, parallel gate arrangements may occur in a random access memory (RAM) as word  
15       lines. However, non-parallel arrangements of gates may have larger contact areas and thus also benefit from the present invention.

          A comparison of contact area width between a preferred embodiment and a conventional approach that includes a liner, may be understood with reference to a number of examples set forth in Tables 1 and 2.

Feature	Target Size ( $\mu\text{m}$ ) (conventional)	Variation ( $\mu\text{m}$ ) (conventional)	Target Size ( $\mu\text{m}$ ) (embodiment)	Variation ( $\mu\text{m}$ ) (embodiment)
Poly Pitch	0.460	NA	0.460	NA
Poly CD Final	0.160	0.030	0.160	0.030
2 x Sidewall	0.140	0.030	0.140	0.030
2 x Liner	0.100	0.010	0.000	0.000
Contact Bottom CD	0.060	0.044	0.160	0.042
Mask Opening Overlay	0.069	NA	0.069	NA

Table 1

Mask Opening CD ( $\mu\text{m}$ )	Contact Bottom CD ( $\mu\text{m}$ ) (conventional)	Contact Bottom CD Worst ( $\mu\text{m}$ ) (conventional)	Contact Bottom CD ( $\mu\text{m}$ ) (embodiment)	Contact Bottom CD Worst ( $\mu\text{m}$ ) (embodiment)
0.20	0.06	0.014	0.1025	0.070
0.21	0.06	0.014	0.1075	0.075
0.22	0.06	0.014	0.1125	0.080
0.23	0.06	0.014	0.1175	0.085
0.24	0.06	0.014	0.1225	0.090
0.25	0.06	0.014	0.1230	0.090
0.26	0.06	0.014	0.1230	0.090
0.27	0.06	0.014	0.1230	0.090
0.28	0.06	0.014	0.1230	0.090
0.29	0.06	0.014	0.1230	0.090
0.30	0.06	0.014	0.1230	0.090
0.31	0.06	0.014	0.1230	0.090
0.32	0.06	0.014	0.1230	0.090
0.33	0.06	0.014	0.1230	0.090

Table 2

5 Table 1 sets forth various feature sizes. Different features in column 1 of Table 1 include a "poly pitch," that can represent the pitch of two parallel conducting structures (such as two polysilicon lines that may form transistor gates). A "poly CD final" can represent the width of a poly line. A "2x Sidewall" can represent the area between adjacent polysilicon lines that is occupied by opposing sidewalls. A "2x Liner" can represent the area between

adjacent polysilicon lines that is occupied by opposing residual liner portions. A "contact bottom CD" can represent a resulting width of a contact bottom. A "mask opening overlay" can represent an alignment offset between a contact etch mask opening and the above-mentioned polysilicon lines.

5           Various feature values and corresponding variations in such values for a conventional example are set forth in columns 2 and 3 of Table 1. An example according to an embodiment is shown in columns 3 and 4. In the conventional case example, residual liner portions may consume 0.100  $\mu\text{m}$ . However, in the example of an embodiment, there is no liner, therefore the "2x Liner" value is zero.

10           Table 2 includes the resulting contact areas for various mask opening values. In column 1 of Table 2, mask opening values vary from 0.20  $\mu\text{m}$  up to 0.33  $\mu\text{m}$ , in increments of 0.01  $\mu\text{m}$ . Columns 2 and 3 set forth a bottom CD value (representing a contact opening) including a worst case value, for a conventional case. Columns 4 and 5 set forth a bottom CD value and worst case value according to an embodiment.

15           As shown by columns 2 and 3 of Table 2, a bottom CD value remains at 0.06  $\mu\text{m}$ , with a worst case of 0.014  $\mu\text{m}$ . Due to the encroachment of a liner and the size of the space between adjacent polysilicon lines (which is 0.16  $\mu\text{m}$ ) variations in contact opening size do not result in any increase in a bottom CD value.

            As shown by columns 4 and 5 of Table 2, contact bottom CD value in an embodiment  
20   can range from 0.1025  $\mu\text{m}$  and reach a maximum of 0.123  $\mu\text{m}$ . In this way, greater contact area can result by providing a contact forming method that does not include a liner.

            A number of embodiments have been described setting forth approaches to forming a contact hole and/or forming a self-aligned contact hole. Such approaches may be

implemented in existing fabrication systems to take advantage of the benefits of the various methods and structures described. As just one example, a manufacturer may change its current fabrication process to skip a liner forming step and subsequent liner removal step. Alternatively, or in addition, an insulating layer according to embodiments may be formed  
5 and a densifying and/or a reflow step may be skipped.

Further, by utilizing the advantageous thermal budget illustrated by the disclosed embodiments, a manufacturer may be capable of re-tooling a fabrication process to accommodate smaller geometry transistors, as the undesired diffusion of dopants from substrate diffusion regions may be more tightly controlled. In addition, or alternatively,  
10 lower resistance contacts may be formed. This may allow contact sizes to be decreased and/or improve integrated circuit operating speeds.

It is understood that while the various particular embodiments have been set forth herein, methods and structures according to the present invention could be subject to various changes, substitutions, and alterations without departing from the spirit and scope of the  
15 invention.